TEST PLAN and Results

COMPLETION INFORMATION

Completion Date: 9/11/96

Test Plan Title: Helium + rf processing of NL03

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Brief Purpose of Test

Rf cavities are frequently limited in their ability to sustain high gradients by the occurrence of field emission from localized spots in high-field regions. A technique historically applied during laboratory testing of SRF cavities to reduce the field emission is low-pressure helium gas processing with rf. Helium gas at less than discharge pressures (~10^{-4} torr) is admitted inside the cavity and rf is applied. Helium, locally ionized by the FE source, back sputters the emitting site and/or creates a localized plasma, frequently reducing the strength of the emitter permanently. After processing, the helium is pumped out. To regain beamline vacuum compatible with beam ops, this probably implies a temperature cycle above 15 K with clean turbopump evacuation.

This test will apply helium processing to NL03, which has several cavities significantly limited by field emission and arcing.

Anticipated Benefits

Development and demonstration of technique to obtain:

Reduced field emission loading of an installed operational cryomodule, which shows itself in reduced radiation, reduced arcing, and improved Q at elevated gradients, thus extending the energy reach of the accelerator and improving reliability.

Beam Conditions Required

REQUIRED INFORMATION: CW or pulsed beam? Desired current and energy. Beam termination point (i.e., 45 MEV dump, N. Stub dump, BSY dump, etc.). Is the test invasive or noninvasive?

downtime, power permit plus occasional controlled accesses - quite invasive

Time Required

7 shifts, warm up, cooldown, 3 shifts

Preferred Time of Test

September down

Staff Required to Execute the Test (including contact info)

Chas. Reece X7645, Ganapati Myneni X7657, Mike Drury x7493 + others

Controlled Access Requirements

To valve in or out turbo pump and add helium precharge.

Hardware and/or Software Changes Required

Set up taps for NL03 to 10.4kv+5% = 10.92kv > 4300kW

Download high GSET_max values to enable stressing.

Setup Procedure

PRELIMINARY SETUP STEPS

1. Move needed mechanical equipment into the tunnel.

- ***a.*** drop needed additional cabling through penetrations - coordinate with other work for shielding fill removal.
- ***b.*** clean turbopump
- ***c.*** gas supply and control system
  The calibrated volume is made by Vacuum Technology Inc. The volume is 493.6 cc and the calibration is traceable to NIST.

  The pressure of the high purity helium 99.999% in the calibrated volume is monitored by Type 127A 100 torr full scale Baratron from MKS Instruments.

  The Servo driven remote controlled valve model is 216 and made by Granville-Phillips corp.

2. Isolate the CM - close beamline valves.

3. Establish turbo pump ready for pumping on beamline, but valved out.

4. Establish pressure monitoring with RGA from Stanford Research Systems, model number is SRS RGA100, viewable from NLSB.

5. Position GM tubes at either end of the module and position between each pair of warm rf windows.

6. Precheck gas delivery system - standard volume charged and pressure reading active.

7. Establish that system is leak tight and stable.

8. Prior to patch-in of the commissioner, measure radiation production versus GMES for cavities 2, 3, 4, 6, 7, 8.

9. Establish gradient and radiation measurement references for cross-calibrating

GREAL with subsequent measurements with the commissioner.

10. Select two field levels for each cavity for making Q measurements. The gradients should be demonstrably above onset of radiation production, separated by at least 1 MV/m, and reasonably stable.

11. Set up commissioner for Q measurements.

12. Bugger interlocks to enable rf without beamline vacuum ion pump ok - this is done by (1) ensuring that pump controller is off (2) disconnecting pump cable at the back of the controller, (3) turning pump controller back on (4) noting the change in the operations log.

13. Establish power permit.

Test Procedure

TEST PROCEDURE STEPS

1. **Make Q_0 measurements at the assigned levels for cavities 2, 3, 4, 6, 7, 8. Record radiation levels at each gradient where Q_0 is measured.**

2. **Select cavity 2 and establish CW rf at field level of interest.**

3. **Admit helium in metered quantities**

   a. 2 torr-liters

   b. add He in controlled increments as necessary for rf processing effectiveness.

   c. target helium pressure range is 2–4 e-4 torr indicated by RGA from Stanford Research Systems, model number is SRS RGA100.

4. **Expect to encounter a low-field (<1MV/m) multipacting barrier when helium is present. Use the commissioner in pulsed mode only to establish the nominal PLL phase and VCO tune. Otherwise, run CW to avoid difficulties with multipacting.**

5. **Observe and record correlated behavior of rf stored energy and radiation production. Establish a reference radiation level and seek to maintain the level as the gradient is increased or operated cavity at highest gradient that can be stably maintained. Note any arcing behavior.**

6. **Repeat steps 6–8 with other cavities while maintaining indicated helium partial pressure.**

7. **Close inlet JT valve. Keep RT valve open.**

8. **Reinstall heater fuses. Allow the normal rf compensation heaters to boil off helium. This module does not have fully functional heaters, so boiloff will be slow in this mode. This is convenient this time, since the boiloff is during an unattended weekend with no schedule pressure.**
[If one applied 150 watts, this with ~15 watts static heat load would empty the CM in about 6.7 hours.]

Test Results

Table 1: Helium Processing on NL03 September 1996

Date	9/2	9/4		9/5					9/6							9/10		9/11	10/7
Cavity	GSET. DRVH	G (MV/m)	Q_0 (10^9)	G (MV/m)				(Pumping w/ turbo 48 min)	G (MV/m)							G (MV/m)	Q_0 (10^9)	Stressed G (MV/m)	GSET. DRVH (MV/m)
1	4.9																	7.0	5.5
2	4.2[a]	7.68	1.5	7.2	9.1	7.7	b				7.7 – 9.1					7.8	3.3	8.5	6.0
3	4.75	7.8	1.6													7.8	1.5	6.8	4.75
4	5.4	8.7	2.5												8.7	8.7	4.1	—	6.38
5	4.4[a]	—	—															—	4.4
6	4.53[a]	6.8	2.1									6.9	6.9			7.15	5.3	8.4	5.9
7	4.3[a]	7.0	0.3											7				8.6	6.3
8	5.0[a]	8.8	2.85	8.8			b		8	7–8						8.8	4.7	8.77	6.0
processing duration (min)					20	45			80	50	90	40	20	65	45				
RGA He pressure indication (10^{-5} torr)		(10^{-11} torr)		3.3	3.3	46.	+46		3.7 – 3.3	32.	20–14	6	25	12–5.7	47	(< $3*10^{-10}$ torr)			
He charge (torr-liters)		0		1.8	1.8	4.3	4.65		2+A	2.52 +A	2.52 +A	2.52 +A	2.91 +A	2.91 +A	4.1+ A	0			
						processing	helium discharge								warmup to 20K and refill				

a. limited by arcing
b. helium discharge observed

Comments

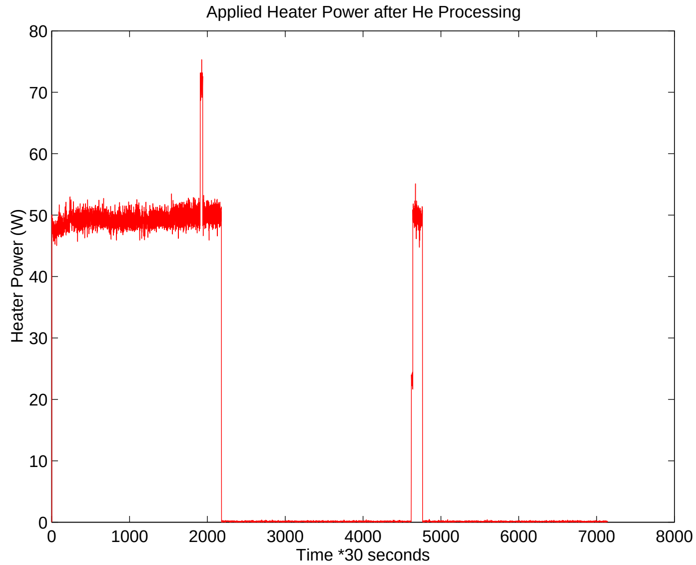
- 4.65 torr-liters @ 2.0K produces helium discharge at the supply end pair.
- The helium pressure relaxation time at the supply end is several hours in the 10^{-4} torr range.
- 4.3 torr-liters @ 2.0K is clearly adequate to produce processing and is below that necessary to produce he discharge.
- With He pressure in the 10-6 range or higher, multipacting barrier was encountered in all cases.
- Application of rf in a cavity speeds up helium migration rate dramatically, as indicated by the pressure reading at the supply end. After addition of additional helium, running rf in cavity 8 produced decrease in indicated helium pressure at the supply end.
- There was no difficulty providing and controlling a He flow rate of $8.3 \cdot 10^{-4}$ L/s into the beamline.
- Processing was observed with helium partial pressure of $1.2–4.7 \cdot 10^{-4}$ torr indicated by the RGA.
- After nominal equilibrium is reached, the indicated pressure increases in direct response to rf operation in a cavity—more than one decade change observed when operating cavity #2.
- C, O, and N partial pressures showed proportional increases with He during rf operation, though in the 10^{-11}—10^{-12} torr range.
- Cavity 5 was not operable during the test for independent reasons.
- Cavity #1 and 3 were not addressed due to time constraints, and were considered lower priority since they had no history of being arc limited.
- The GM tube monitor channel at pair 3/4 was not operable during the test.
- J-T valve closed at 00:07 9/7/96. RT valve remained fully open.
- 2K boiloff with J-T valve closed and indicated 49 watts showed remarkably linear loss of indicated liquid level—0.086%/hr.
- Treating indicated level as volume indicator leads to loss rate of 69L/hr for a heat load of 73 watts total. (Typical static loss is 17 watts.) See Table 2 for handy numbers. The nominal LHe volume at 91% liquid level is 1200L.

Table 2: Reference Helium Parameters

T (K)	Boiloff rate (L/hr)/watt	Volumetric Heat of Vaporization (watt/(L/hr))	density (gm/L)	Heat of Vaporization (J/gm)
4.5	1.59	0.63	125	20.9
4.2	1.38	0.7256	120	19.0
2.0	1.06	0.94	146	23.2

- At 14:50 9/7/96, began pumping on beamline vac with turbo. Initial pressure indication at turbo on opening valve: 2.5e-6 torr. Liquid level indicates 15%.

- Heater turned off ~16:00 9/7/96.
- After heater was turned off, net static loss with RT open was 7.6L/hr, or 8 watts.(Again treating liquid level as volume indicator.)
- Heat reapplied ~12:00-13:30 9/8/96. Heat was reapplied (49 watts) to boiloff remaining liquid and to raise cavity system temperatures > 20K.



- All 4 mid-plane diodes, mounted on the horizontally directed HOM elbows, were monitored. All indicated above 12K for at least one hour.
- Turbo pump pressure indicated $0.9 \cdot 10^{-7}$ torr at 13:15 9/8/96.
- Ion pump restarted at 13:20 9/8/96 and turbo valved off.
- Slight temperature bump when J-T was reopened indicates that the valve was indeed closed.
- J-T began opening ~16:30 9/8/96.
- Cryomodule was back at nominal liquid level—91% indicated—at 08:00 9/9/96. After J-T was opened, refill was unattended, using normal J-T control loops.
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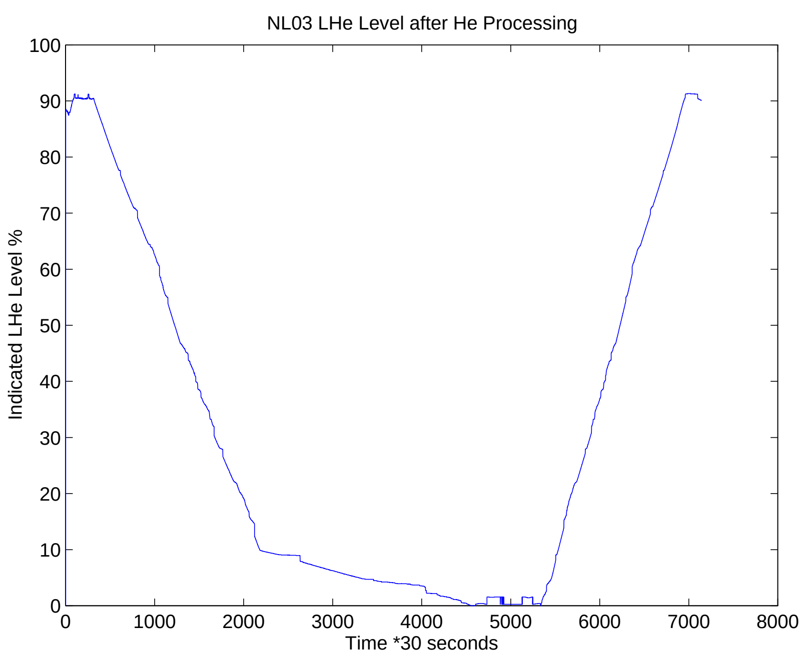

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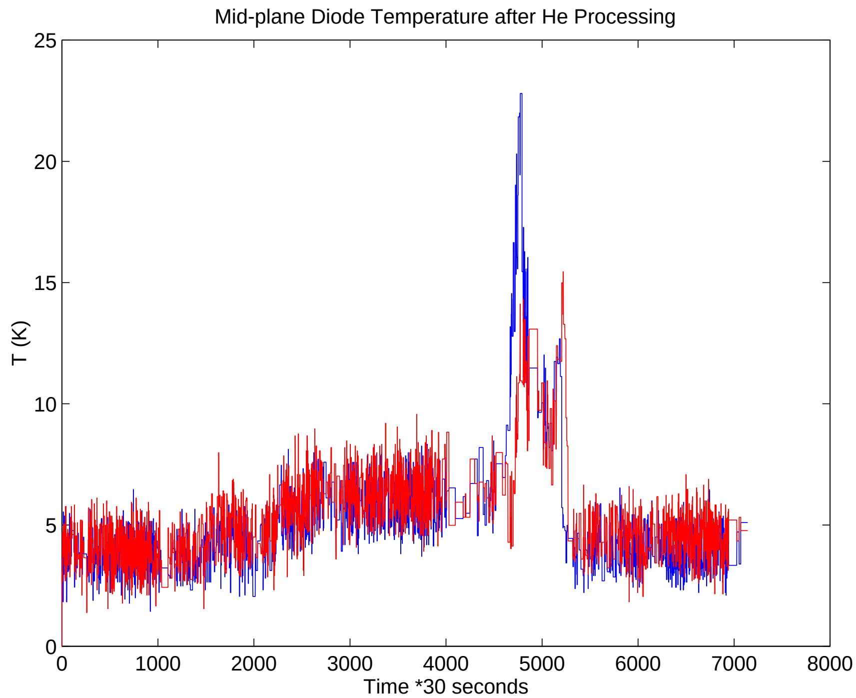

- All arc-limited cavities that were processed, (2, 6, 7 and 8) showed relief from arcing, reduction in radiation production, and increase in high-field Q. [Cavity 7 is exception to Q, as it was otherwise very lossy ($<\cdot 10^9$).] See tables 1 and 3.
- After warm-up and cooldown, radiation patterns were found to have shifted to higher gradients for all cavities processed and all monitored locations. See figures.
- There was no difficulty reestablishing beamline vacuum.
- In every respect, NL03 performed better in operation after the helium processing.

Table 3: Relief from arcing and FE loading after helium processing of NL03

Cavity	Max G before processing (MV/m)	limitation	Max G after processing (MV/m)	% improvement
2	4.2	arcs	8.5	102
4	5.4	FE loading	8.8	62
6	4.5	arcs	7	56
7	4.3	arcs	6.3	47
8	5.0	arcs	8.0	60

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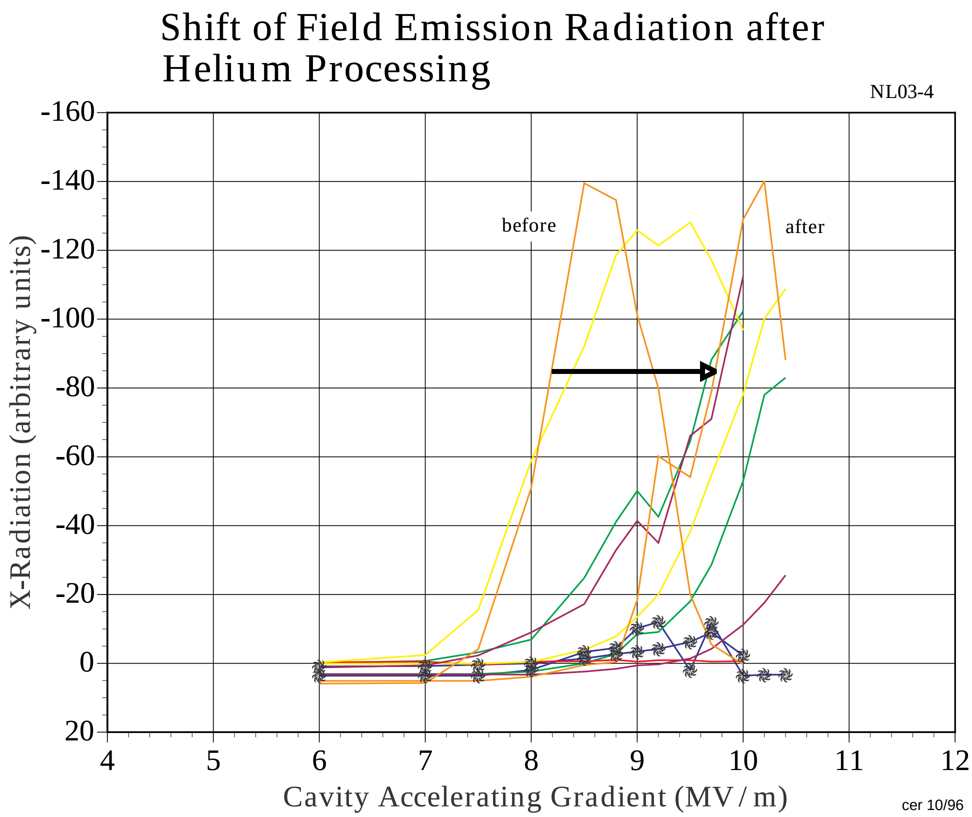
Shift of Field Emission Radiation after
Helium Processing
NL03-4
before
after
X-Radiation (arbitrary units)
-160
-140
-120
-100
-80
-60
-40
-20
0
20
4
5
6
7
8
9
10
11
12
Cavity Accelerating Gradient (MV / m)
cer 10/96